

## EEG SONIFICATION FOR EPILEPSY SURGERY: A CLINICAL WORK-IN-PROGRESS

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### ABSTRACT

Although EEG sonification has been well studied, its potential to identify seizure foci in patients undergoing epilepsy surgery has received little attention. We explore the sonification requirements needed for this application, and discuss a preliminary approach that has identified an auditory marker for epileptic tissue that agrees with standard EEG. Development of these early ideas into a clinical tool would be a welcome addition to the epilepsy surgery evaluation.

### 1. INTRODUCTION

As many as a third of patients with epilepsy will continue to have seizures despite optimal treatment with medication [1]. Because continued seizures can lead to neurologic decline and death, surgery may be offered to remove the portion of the brain in which the seizure begins (the 'seizure focus'). The decision for surgery is not trivial, and patient selection protocols are extensive. Foremost among these is the video-EEG, in which simultaneous real time video and EEG recordings are obtained continuously over several days in order to correlate the behavior of the patient during each seizure with the EEG. If the seizure type matches the EEG and other data, surgery can be offered.

In order for surgery to be effective, the seizure focus must be removed. Unfortunately, identifying seizure foci with EEG can be subtle, because they are heralded by low amplitude changes that are difficult to see and confounded by normal and abnormal rhythms as well as artifact. Failure to identify the focus is therefore not unusual, and can be discouraging for the epilepsy team and devastating to the patient for whom surgical options are blocked.



Figure 1: Grid of EEG contacts placed directly on the brain of one of our patients for seizure detection.

We describe a first approach to use EEG sonification to identify the seizure focus in EEG recordings obtained for evaluation for seizure surgery. Our hope is that the sophisticated auditory capabilities of the human ear can augment the more standard visual analysis of EEG data.

### 2. REQUIREMENTS OF EPILEPSY SURGERY

Specific demands of the surgical evaluation constrain our audification strategy in three ways. First, although the data can be analyzed offline, they must be viewed in real time to allow comparison with the video recordings. Second, it may be advantageous to analyze the EEG spectrum directly rather than use more sophisticated parameter mapping or event-based models [2,3]. This is because the goal is not to detect the seizures themselves – they are easily revealed by the EEG/video data – but rather, to detect EEG synchronies occurring shortly before the seizure that identify the first site of seizure onset. Because it is unclear which features of these synchronies are most important, and because it is precisely this data that sonification is to explore, we are reluctant to abandon the rich detail of the full spectrum. Furthermore, seizures considered for surgery are less stereotypical and less predictable than those of many other types of epilepsy, making the choice of parameters or models difficult. We therefore favor a more direct audification approach, at least at this early stage of our experience. Third, EEG data in the delta (<4 Hz), gamma (25 to 100 Hz) and ripple (100 to 500 Hz) ranges are valuable to epileptologists because activity in the first is an important indicator of epileptic tissue and activity in the others – especially the ripple range – is an important indicator of seizure onset [4]. This bandwidth is larger than has been previously considered [2,3] and poses special challenges to direct audification.

### 3. METHODS AND RESULTS

We present an early preliminary analysis of EEG data obtained from our patients being evaluated for seizure surgery.

#### 3.1 Data and Conditioning

EEG recordings were obtained from electrodes surgically implanted in the brains of 5 patients being treated and operated upon by us for intractable epilepsy. Data from implanted electrodes were chosen rather than from scalp electrodes because they are relatively free from artifact, sample a more specific volume of brain tissue, and have known location relative to the proven seizure foci. Each recording contained data from the few minutes prior to a seizure, the seizure itself,

and a few minutes afterwards. The data was bandwidth filtered (time constant 2.0 seconds, low pass 70 Hz), sampled at 200 Hz and passed to the Matlab environment. The filter threshold of 70 Hz used for clinical work prevented examination of the gamma and ripple bands. Channels obtained from sites that later proved to be seizure foci were compared with channels obtained from sites without initial seizure activity.

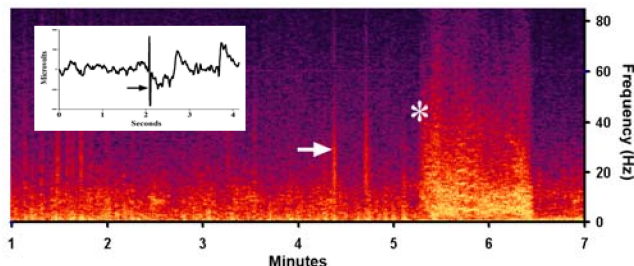


Figure 2: Time-frequency plot of EEG from implanted electrode in patient with seizures. Arrow indicates a 'shimmer'. Asterisk indicates start of seizure. Inset shows spike in raw EEG (arrow) corresponding to same 'shimmer'. Note difference in time scale.

### 3.2 Audification and Data Analysis

Vocoder software [5] was used to slow the timebase of each recording without changing the pitch of the EEG frequencies. An audio file was written from these slowed recordings using a high sampling rate to increase the EEG frequencies into the audible range. If  $f$  is the original sampling rate and  $1/r$  is the factor by which the vocoder changes the timebase, then increasing the sampling rate from  $f$  to  $fr$  produces a recording in real time with frequencies altered by a factor of  $r$ . We chose to use  $r = 200$  to shift the delta-to-gamma range of 1 to 70 Hz to the audible range of 200 to 14000 Hz.

The recordings were examined with software (Soundbooth, Adobe, San Jose, California) allowing visual examination of the waveform, its time-frequency spectrum, and auditory review of the recording. Frequency ranges of audible tones were correlated to bands visible on the time-frequency spectrum and to the raw EEG. Auditory review included the entire spectrum as well as selected isolated frequency bands.

### 3.3 Results

Artifact arising from the vocoder algorithm could be minimized by using short windows (512 points, 2.6 seconds) and small overlaps. Short segments of high pitched, high amplitude signals (1 to 2 seconds, 1 to 4 kHz) that could be described as acoustic 'shimmers' were frequent in tissue that eventually developed seizures, but were rare in normal tissue. Review of the EEG showed that they arise from 'spikes' in the EEG waveform that are classical makers of epileptogenicity. The well-known  $1/f$  character of the EEG was apparent in the audio signals [6], with lower frequencies having higher amplitude than higher frequencies. In some cases, widening the lowpass filter allowed demonstration of frequencies in the ripple range as indentations superimposed on the  $1/f$  shape of the EEG spectrum.

## 4. DISCUSSION AND FUTURE DIRECTIONS

The specific demands of using EEG sonification to find seizure foci in patients being evaluated for epilepsy surgery – the need for real time review, the uncertainty of key parameters, and the wide range of required frequencies – impose constraints on the sonification. Barriers include vocoder artifacts and the lack of classification of the auditory EEG data. Our early data identify audible features of the EEG ('shimmers') corresponding to classical markers of epileptogenicity ('spikes').

Perhaps the most important task is to determine if sonification can augment the already sophisticated visual EEG review. Plans are underway to establish workstations at our institution allowing auditory review of EEG data during the routine review of the clinical data. After gaining experience correlating these data, the hypothesis that auditory EEG can improve foci detection will be tested with a randomized trial using existing data for which the location of the seizure foci is known. At the same time, various listening strategies and technical refinements (e.g., methods such as differentiation to alter the  $1/f$  shape of the EEG spectrum to better hear frequencies in the ripple range, algorithms to reduce vocoder artifact, and audification methods allowing auditory display of the entire range of epilepsy frequencies of 1 to 500 Hz) will be explored. Collaboration with established sonification groups will be actively sought.

## 5. CONCLUSION

We explore EEG sonification as an aid to the identification of seizure foci for epilepsy surgery. Development of this early experience into a clinical tool would be a welcome addition to those making these difficult decisions.

## 6. REFERENCES

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